

The Trivial Higgs at LHC

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Abstract

We further elaborate on our proposal for the Trivial Higgs that within the Standard Model is the unique possibility to implement the spontaneous symmetry breaking of the local gauge symmetry by elementary local scalar fields. The Trivial Higgs boson turns out to be rather heavy with mass $m_H \simeq 750$ GeV. We discuss the experimental signatures of our Trivial Higgs and compare with the recent data from ATLAS and CMS collaborations based on a total integrated luminosity between 1 fb^{-1} and 2.3 fb^{-1} . We suggest that the available experimental data could be consistent with our scenario.

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I. INTRODUCTION

In a previous paper [1] we have enlightened the scenario where the Higgs boson without self-interaction (Trivial Higgs) could coexist with spontaneous symmetry breaking. Due to the peculiar rescaling of the Higgs condensate, the relation between m_H and the physical v_R is not the same as in perturbation theory. According to this picture one expects that the ratio m_H/v_R would be a cutoff-independent constant. In fact, our numerical results [1] showed that the extrapolation to the continuum limit leads to the quite simple result:

$$m_H \simeq \pi v_R, \quad (1)$$

pointing to a rather massive Trivial Higgs boson $m_H \simeq 750$ GeV.

A cornerstone of the Standard Model is the mechanism of spontaneous symmetry breaking that is mediated by the Higgs boson. In fact, the discovery of the Higgs boson is the highest priority of the Large Hadron Collider (LHC). Recently, both the ATLAS and CMS collaborations [2, 3] reported the experimental results for the search of the Higgs boson at the Large Hadron Collider running at $\sqrt{s} = 7$ TeV, based on a total integrated luminosity between 1 fb^{-1} and 2.3 fb^{-1} .

The aim of the present paper is to further elaborate on the production mechanisms of our Trivial Higgs and to compare the theoretical expectations with selected available data from LHC.

II. THE TRIVIAL HIGGS

For Higgs mass in the range $700 - 800$ GeV the main production mechanism at LHC is the gluon fusion $gg \rightarrow H$. The theoretical estimate of the production cross section at LHC for centre of mass energy $\sqrt{s} = 7$ TeV is [4] :

$$\sigma^{SM}(gg \rightarrow H) \simeq 0.06 - 0.14 \text{ pb} \quad , \quad 700 \text{ GeV} < m_H < 800 \text{ GeV} . \quad (2)$$

The gluon coupling to the Higgs boson in the Standard Model is mediated by triangular loops of top and bottom quarks. Since the Yukawa coupling of the Higgs particle to heavy quarks grows with quark mass, thus balancing the decrease of the triangle amplitude, the effective gluon coupling approaches a non-zero value for large loop-quark masses. On the other hand, we already argued [1] that the non trivial rescaling of the Higgs condensate means that, if

the fermions acquires a finite mass through the Yukawa couplings, then the coupling of the physical Higgs field to the fermions could be very different from the perturbative Standard Model Higgs boson. However, the coupling of the Higgs field to the gauge vector bosons is fixed by the gauge symmetries, therefore the coupling of the Trivial Higgs boson to the gauge vector bosons is the same as for the Standard Model Higgs boson. For large Higgs masses the vector-boson fusion mechanism becomes competitive to the gluon fusion Higgs production [4]:

$$\sigma^{SM}(W^+ W^- \rightarrow H) \simeq 0.02 - 0.03 \text{ pb} \quad , \quad 700 \text{ GeV} < m_H < 800 \text{ GeV} . \quad (3)$$

The main difficulty in the experimental identification of a very heavy Higgs ($m_H > 650 \text{ GeV}$) resides in the large width which makes impossible to observe a mass peak. In fact, the expected mass spectrum of our trivial Higgs should be proportional to the Lorentzian distribution:

$$L_H(E) \sim \frac{\Gamma}{(E - 750 \text{ GeV})^2 + \Gamma^2} \quad , \quad (4)$$

where we assume the central value of the Higgs mass according to Eq. (1) and Γ is the Higgs total width. Note that Eq. (4) is the simplest distribution consistent with the Heisenberg uncertainty principle and the finite lifetime $\tau \simeq 1/\Gamma$.

According to the triviality and spontaneous symmetry breaking scenario the Higgs self-coupling vanishes so that the decay width is mainly given by the decays into pairs of massive gauge bosons:

$$\Gamma \simeq \Gamma(H \rightarrow W^+ W^-) + \Gamma(H \rightarrow Z^0 Z^0) . \quad (5)$$

Since the coupling of the Trivial Higgs to the gauge vector bosons is fixed by the local gauge symmetry, the decay width into gauge vector bosons is the same as in the case of the perturbative Higgs boson, consequently [5]

$$\Gamma(H \rightarrow W^+ W^-) \simeq 2 \Gamma(H \rightarrow Z^0 Z^0) \sim G_F m_H^3 . \quad (6)$$

Equation (6) shows that in the high mass region $m_H \gtrsim 400 \text{ GeV}$ the Higgs total width depends strongly on m_H . To take care of the energy dependence of the width in Eq. (4) we need $\Gamma(E)$ as a function of E . To this end we may follow the calculations of Higgs total width within the Standard Model performed in Ref. [4]. In Fig. 1 (left) we show the energy dependence of the Higgs total width $\Gamma(E)$ according to Tables 28 and 29 of Ref. [4]. We

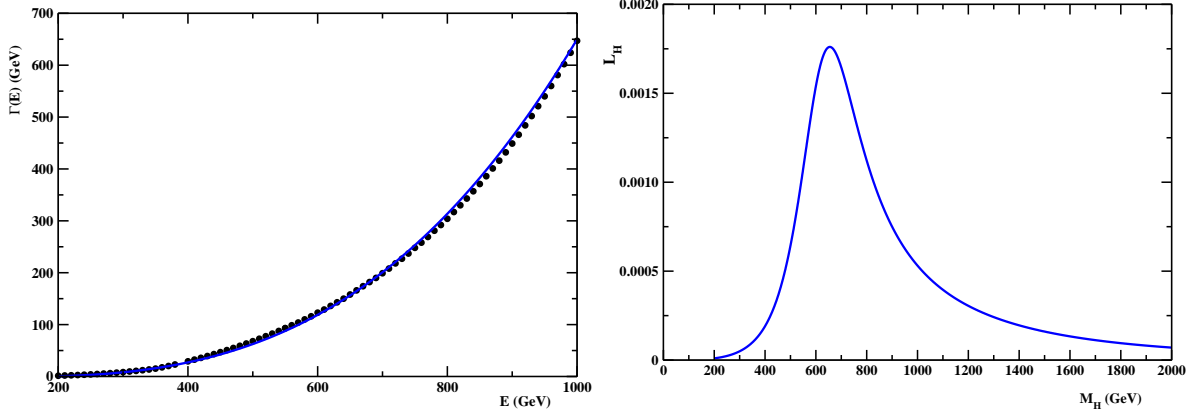


FIG. 1: (Left) The energy dependence of the Higgs total width. Full points are the values of the Standard Model Higgs total widths reported in Tables 28 and 29 of Ref. [4]. The full line is our parameterization Eq. (7). (Right) The Lorentzian distribution Eq. (8) as a function of the Higgs mass M_H .

have fitted the tabulated values of $\Gamma(E)$ with the phenomenological relation (full blue line in Fig. 1, left):

$$\Gamma(E) \simeq 8.0 \cdot 10^{-7} E^3 - 1.5 \cdot 10^{-4} E^2. \quad (7)$$

We obtain, therefore, the following Lorentzian distribution:

$$L_H(E) \simeq \frac{1.465}{\pi} \frac{\Gamma(E)}{(E - 750 \text{ GeV})^2 + \Gamma(E)^2}, \quad (8)$$

where $\Gamma(E)$ is given by Eq. (7), and the normalization is such that:

$$\int_0^\infty L_H(E) dE = 1. \quad (9)$$

In the limit $\Gamma \rightarrow 0$, $L_H(E)$ reduces to $\delta(E - 750 \text{ GeV})$. In Fig. 1 (right) we display the Lorentzian distribution as a function of the energy E .

To evaluate the Higgs event production at LHC we need the Higgs production total cross section. As already discussed, for large Higgs masses the main production processes are by vector-boson fusion and gluon-gluon fusion. The Trivial Higgs production cross section by vector-boson fusion is almost the same as in the perturbative Standard Model calculations. In Fig. 2 (left) we show the energy dependence of the perturbative Higgs boson vector-boson fusion cross section within the Standard Model at $\sqrt{s} = 7 \text{ TeV}$ reported in Table 11 of Ref. [4]. We parametrize the energy dependence of the cross section as (full blue line in

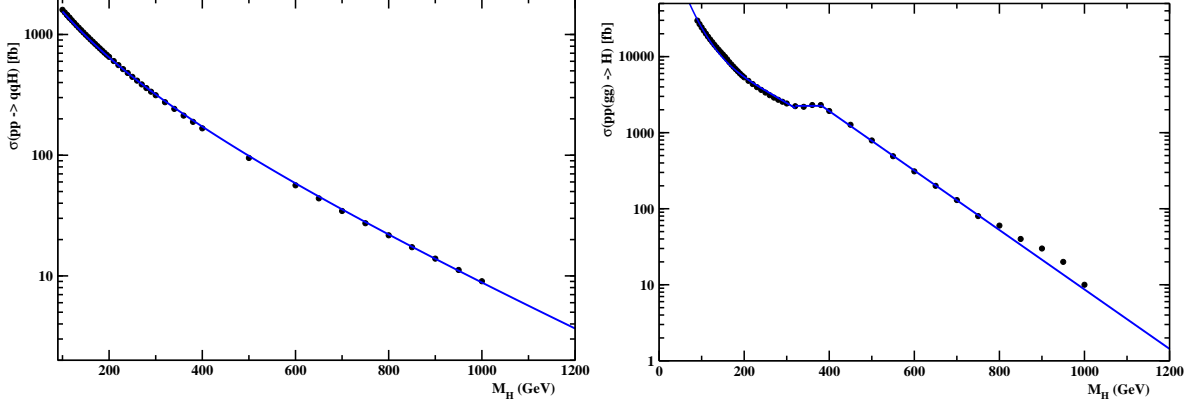


FIG. 2: (Left) The energy dependence of the vector-boson fusion cross section. The full points are the Standard Model Higgs production cross section at $\sqrt{s} = 7$ TeV reported in Table 11 of Ref. [4]. The full line is our parameterization Eq. (10). (Right) The energy dependence of the gluon-fusion cross section. The full points are the Standard Model Higgs production cross section at $\sqrt{s} = 7$ TeV reported in Table 5 of Ref. [4]. The full line is our parameterization Eq. (11).

Fig. 2, left):

$$\sigma^{SM}(W^+ W^- \rightarrow H) \simeq \left(\frac{3.0 \cdot 10^5}{M_H} - \frac{8.0 \cdot 10^6}{M_H^2} \right) \exp(-0.0035 M_H) , \quad M_H \text{ in GeV} . \quad (10)$$

As concern the gluon fusion cross section, in Fig. 2 (right) we display the Standard Model Higgs production cross section at $\sqrt{s} = 7$ TeV reported in Table 5 of Ref. [4]. Again we parametrize the energy dependence of the cross section as (full blue line in Fig. 2, right):

$$\sigma^{SM}(gg \rightarrow H) \simeq \begin{cases} \left(\frac{1.1 \cdot 10^7}{M_H} + 0.0097 M_H^3 \right) \exp(-0.016 M_H) & M_H \leq 320 \\ 2.25 \cdot 10^3 & 320 \leq M_H \leq 380 \\ 2.30 \cdot 10^3 \exp(-0.016 M_H) & 380 \leq M_H \end{cases} \quad (11)$$

where M_H is expressed in GeV.

The gluon coupling to the perturbative Higgs boson in the Standard Model is mediated by triangular loops of top and bottom quarks. On the other hand, as already discussed, the coupling of the Trivial Higgs to the fermions is not fixed by the local gauge symmetry so that there is no a priori reasons to expect that these couplings would be proportional to the fermion masses. However, in the relevant high mass region $m_H \gtrsim 400$ GeV the energy dependence of $\sigma^{SM}(gg \rightarrow H)$ is given essentially by the gluon distribution function. Thus, we may safely assume that the Trivial Higgs production cross section by gluon-gluon fusion

is proportional to $\sigma^{SM}(gg \rightarrow H)$ as given by Eq. (11).

To summarize, our main approximation for the total production cross section of the Trivial Higgs is:

$$\sigma(pp \rightarrow H + X) \simeq \sigma^{SM}(W^+ W^- \rightarrow H) + \kappa \sigma^{SM}(gg \rightarrow H), \quad (12)$$

where the parameter κ takes care of our ignorance on the Yukawa couplings of the Trivial Higgs to the fermions.

To compare the invariant mass spectrum of our Trivial Higgs with the experimental data, we observe that:

$$N_H(E_1, E_2) \simeq \mathcal{L} \int_{E_1}^{E_2} BR(E) \varepsilon(E) \sigma(pp \rightarrow H + X) L_H(E) dE, \quad (13)$$

where N_H is the number of Higgs events in the energy interval E_1, E_2 , corresponding to an integrated luminosity \mathcal{L} , in the given channel with branching ratio $BR(E)$. The parameter $\varepsilon(E)$ accounts for the efficiency of trigger, acceptance of the detectors, the kinematic selections, and so on. Thus, in general $\varepsilon(E)$ depends on the energy, the selected channel and the detector. In our preliminary study we shall adopt the rather crude approximation:

$$\varepsilon(E) \simeq 0.20. \quad (14)$$

As concern the branching ratios $BR(E)$, in the relevant Higgs mass region $m_H \gtrsim 400$ GeV the Higgs decays mainly into pairs of massive gauge bosons. The most important decay channels are $H \rightarrow WW \rightarrow \ell\nu qq$, $H \rightarrow ZZ \rightarrow \ell\ell qq$, $H \rightarrow ZZ \rightarrow \ell\ell\nu\nu$ and $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$. Since the relevant branching ratios are almost independent on the Higgs mass and, assuming the Standard Model values, we are led to use the following values:

$$\begin{aligned} BR(H \rightarrow WW \rightarrow \ell\nu qq) &\simeq 0.438 \\ BR(H \rightarrow ZZ \rightarrow \ell\ell qq) &\simeq 0.153 \\ BR(H \rightarrow ZZ \rightarrow \ell\ell\nu\nu) &\simeq 0.061 \\ BR(H \rightarrow ZZ \rightarrow \ell\ell\ell\ell) &\simeq 0.010 \end{aligned} \quad (15)$$

The above approximations should be sufficient for the preliminary study of interest here.

III. $H \rightarrow WW \rightarrow \ell\nu qq$

For high Higgs mass the decay process $H \rightarrow WW \rightarrow \ell\nu qq$ has the largest branching ratio. Moreover, the presence of charged lepton allows to obtain a good rejection of the QCD

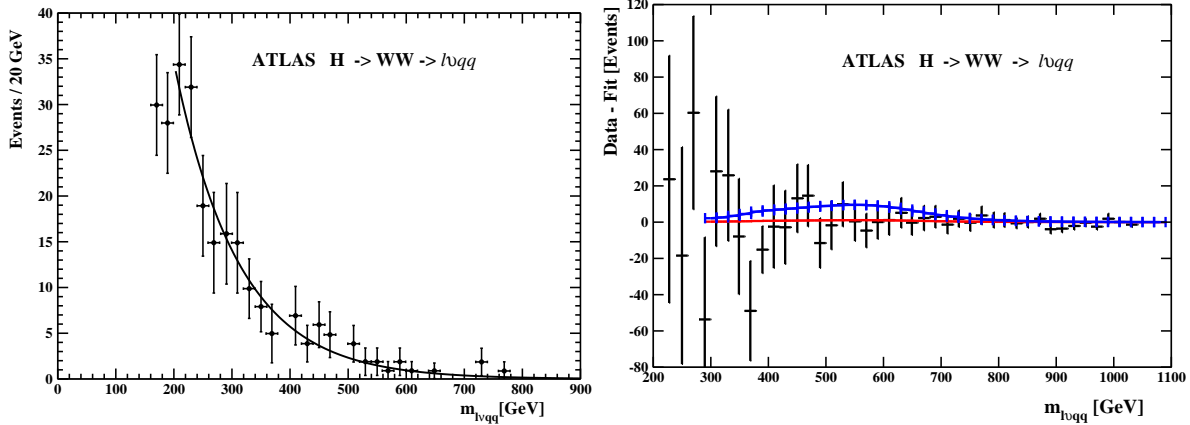


FIG. 3: (Left) Distribution of the invariant mass $m_{\ell\nu qq}$ for the process $H \rightarrow WW \rightarrow \ell\nu qq$ corresponding to an integrated luminosity of 35 pb^{-1} . The data has been extracted from Fig. 4, panel b) of Ref. [6]. The invariant mass continuum background is parametrized as a falling exponential function (full line).

(Right) Comparison of the background subtracted experimental data corresponding to an integrated luminosity of 1.04 fb^{-1} (data taken from Ref. [7]) with the Higgs event distribution according to Eq. (13) binned in energy intervals of 20 GeV assuming $\kappa = 1$ (red line) and $\kappa = 10$ (blue line).

processes. The main background is given by the production of $W + \text{jet}$ which, however, should be suppressed for large invariant mass $m_{\ell\nu qq}$.

Preliminary results from the ATLAS collaboration [6] reported the experimental search of the Higgs boson at the Large Hadron Collider running at $\sqrt{s} = 7 \text{ TeV}$, based on a total integrated luminosity of about 40 pb^{-1} . In particular, in Fig. 3 (left) we display the distribution of the invariant mass for the Higgs boson candidates corresponding to the process $H \rightarrow WW \rightarrow \ell\nu qq$. According to Ref. [6], the events were selected requiring exactly one lepton with $p_T > 30 \text{ GeV}$. The missing transverse energy in the event were required to be $E_T^{\text{miss}} > 30 \text{ GeV}$. The invariant mass continuum background is parametrized as a falling exponential function. It is amusing to see that there are some events in the high invariant mass region which, however, are not statistically significant due to the low integrated luminosity. Recently, an update of search for the Higgs boson in this channel from the ATLAS collaboration corresponding to an integrated luminosity of 1.04 fb^{-1} have been presented in Ref. [7]. In Fig. 3 (right) we display the background-subtracted data.

The large statistical uncertainties, mainly due to the background subtraction, do not show evidence of any structure in the invariant mass distribution.

To compare our theoretical expectation we use Eq. (13) with the branching ratios in Eq. (15). In Fig. 3 (right) we compare the the Higgs event distribution binned in energy intervals of 20 GeV assuming $\kappa = 1$ (red line), i.e. the Standard Model perturbative Higgs production cross section, and integrated luminosity of 1.04 fb^{-1} . We see that our theoretical distribution is compatible with experimental data. Interestingly enough, we find that the experimental data allow an enhanced gluon-gluon fusion cross section, as can be inspected in Fig. 3 (right) where we also display the theoretical Higgs event distribution assuming the total production cross section of the Trivial Higgs is given by Eq. (12) with $\kappa = 10$ (blue line).

In the following Sections we consider the most important Higgs decay channels in order to determine if the enhanced Higgs production by the gluon-gluon fusion process is compatible with available experimental observations.

IV. $H \rightarrow ZZ \rightarrow \ell\ell qq$

The decay channel $H \rightarrow ZZ \rightarrow \ell\ell qq$ has the highest rate among all the processes where the Higgs boson decays into two Z bosons. The search strategy is to find some structures in the invariant mass $m_{\ell\ell qq}$. The major background is due to processes with production of $Z + \text{jet}$. In Fig. 4 we report the experimental data from ATLAS (left) and CMS (right) collaborations. Our theoretical expectations obtained from Eq. (13) are compared with the data (compare also with Fig. 10, panel c) of Ref. [9]). We see that our Higgs event distribution is not in contradiction with the experimental data, even though we cannot exclude that the data are compatible with the background-only hypothesis.

V. $H \rightarrow ZZ \rightarrow \ell\nu\nu$ & $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$

The channels $H \rightarrow ZZ \rightarrow \ell\nu\nu$ and $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$ have the lowest branching ratios, see Eq. (15). Nevertheless, the presence of leptons allows to efficiently reduce the huge background due mainly to diboson production.

In Fig. 5 (left) we display the distribution of the missing transverse energy for the channel $H \rightarrow ZZ \rightarrow \ell\nu\nu$ corresponding to an integrated luminosity of 1.04 fb^{-1} . The data from

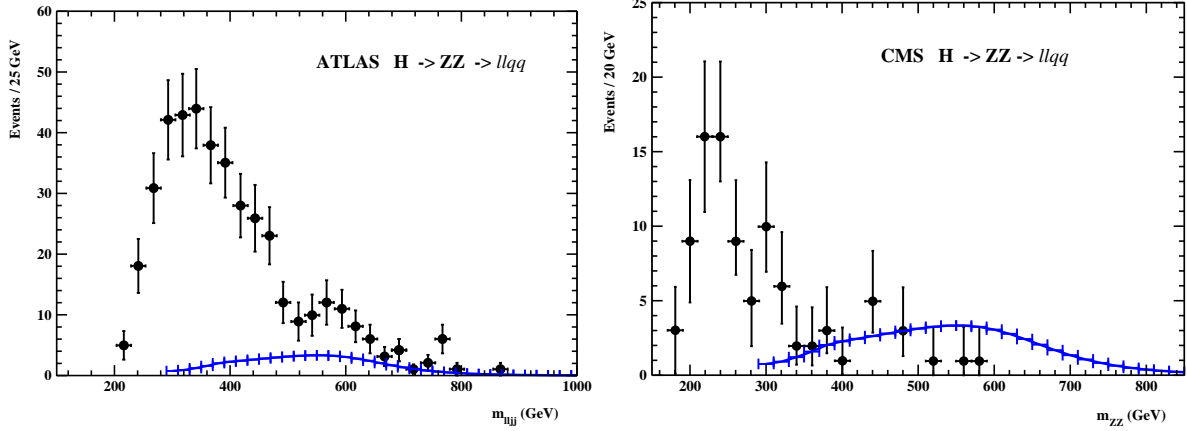


FIG. 4: (Left) Comparison of the distribution of the invariant mass $m_{\ell\ell qq}$ for the process $H \rightarrow ZZ \rightarrow \ell\ell qq$ corresponding to an integrated luminosity of 1.04 fb^{-1} with the Higgs event distribution according to Eq. (13) binned in energy intervals of 20 GeV assuming $\kappa = 10$ (blue line). The data from the ATLAS Collaboration have been extracted from Fig. 2, panel c) of Ref. [8].

(Right) Comparison of the distribution of the invariant mass m_{ZZ} for the process $H \rightarrow ZZ \rightarrow \ell\ell qq$ corresponding to an integrated luminosity of 1.6 fb^{-1} with the Higgs event distribution according to Eq. (13) binned in energy intervals of 20 GeV assuming $\kappa = 10$ (blue line). The data from the CMS Collaboration have been extracted from Ref [3].

the ATLAS collaboration have been taken from Ref. [8]. In the high mass region $m_T \gtrsim 400$ GeV, where the background is strongly suppressed, there are a few events which compare well with our theoretical prediction assuming an enhanced gluon fusion cross section, $\kappa = 10$.

In Fig. 5 (right) we report the invariant mass distribution for the golden channel $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$ with integrated luminosity $1.96 - 2.28 \text{ fb}^{-1}$ from the ATLAS collaboration [8]. Even in this channel there are a few events in the high invariant mass region which are in fair agreement with our Higgs event distribution with $\kappa = 10$ and $\mathcal{L} \simeq 2.0 \text{ fb}^{-1}$.

VI. CONCLUSION

To conclude, we argued that strictly local scalar fields are compatible with spontaneous symmetry breaking. We stress that within the Standard Model our proposal is the unique possibility to implement the spontaneous symmetry breaking of the local gauge symmetry

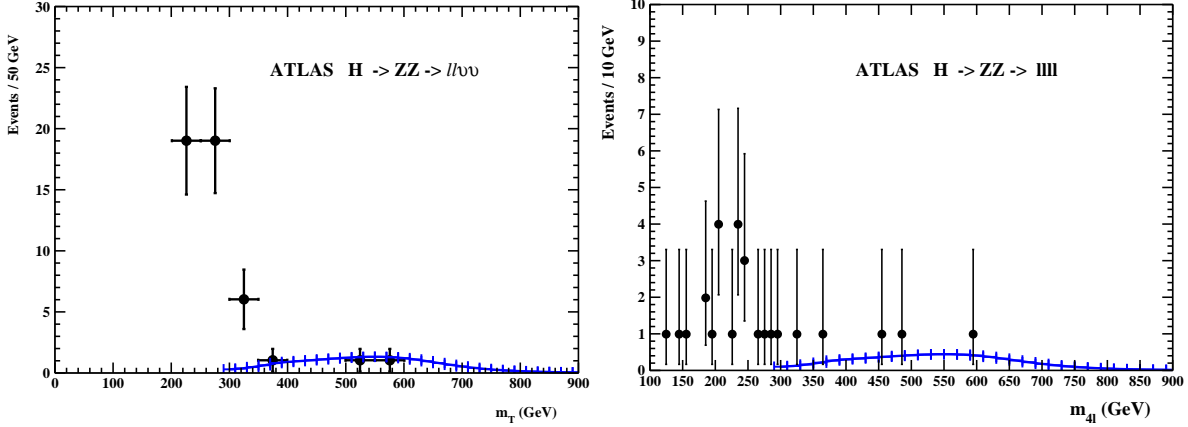


FIG. 5: (Left) Comparison of the distribution of the transverse mass m_T for the $H \rightarrow ZZ \rightarrow \ell\nu\nu$ channel corresponding to an integrated luminosity of 1.04 fb^{-1} with the Higgs event distribution Eq. (13) binned in energy intervals of 20 GeV assuming $\kappa = 10$ (blue line). The data from the ATLAS Collaboration have been extracted from Fig. 2, panel e) of Ref. [8].

(Right) Comparison of the distribution of the invariant mass $m_{4\ell}$ for the process $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$ corresponding to an integrated luminosity of $1.96 - 2.28 \text{ fb}^{-1}$ with the Higgs event distribution according to Eq. (13) binned in energy intervals of 20 GeV assuming $\kappa = 10$ and $\mathcal{L} \simeq 2.0 \text{ fb}^{-1}$ (blue line). The data have been extracted from Fig. 1, panel b) of Ref. [8].

by elementary local scalar fields. Our Trivial Higgs boson turns out to be rather heavy. We compared our proposal with the recent results from ATLAS and CMS collaborations and gave some evidence that experimental data are not in contradiction with our scenario. Of course, it should be emphasized that the data could be compatible with the background-only hypothesis. We suggested that the Yukawa couplings of the Trivial Higgs could be very different from the perturbative Standard Model Higgs boson. In particular, there are no compelling reasons to expect that the couplings of the Trivial Higgs to fermions are proportional to the fermion mass. As a consequence, we do not have enough arguments to set constraints on the Higgs production by the gluon-gluon fusion processes. Nevertheless, it is remarkable that the available data allow us to set an upper limit $\kappa \lesssim 10$ to the gluon fusion Higgs production cross section.

We are confident that in the near future forthcoming data from LHC will confirm our Trivial Higgs proposal. In the most favourable case of an enhanced gluon fusion cross section $\kappa \lesssim 10$ an integrated luminosity of order 10 fb^{-1} will be enough to confirm our scenario. On

the other hand, if the gluon fusion cross section turns out to be suppressed with respect to the Standard Model perturbative Higgs boson, $\kappa \lesssim 1$, then we must wait for an integrated luminosity of several hundred of fb^{-1} .

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